sensitivity. Additional advantages are the use of differential detection that will reduce the low-frequency noise and improve the angle-random walk, as compared with detection methods that do not allow for differential detection.

In accordance with features of the present invention, a magnetic field sensing device is disclosed that includes a cell adapted for containing alkali atoms at a their vapor pressure so that the alkali atoms can become polarized, a light source producing a spatially diverging or converging light field, a wave plate to circularly polarize light from the light source, at least one photodetector adapted to measure magnetic field strength based on a reaction of the light with the alkali atoms. A flex circuit adapted to provide signals from the at least one photodetector to a computer (adapted as external signal conditioning and detection circuitry facilities) can also be included. A heater can also be included, wherein the heater is used to heat the cell and a thermal sensor is used to stabilize the temperature at a predetermined value. The apparatus can be adapted in a gyroscope implementation that comprises a magnetic shield and an additional gas. Any noble gas with a non-zero nuclear spin can be used, including ^{129}Xe.

In accordance with a method of using the present invention, light emitted from a light source passes through a set of optics adapted to circularly polarize light from the light source, attenuate the light and change its spatial mode. The resulting light field has a spatially converging or diverging profile. The light passes through a cell. An oscillating magnetic field is generated at a Larmor frequency of the alkali atoms in a direction along the average light propagation direction with a component perpendicular to said magnetic field with at least one of a plurality of coil. To adapt the magnetometer for use as an NMR gyroscope, an oscillating magnetic field at the Larmor frequency of the noble gas atoms is also applied to the cell. An atomic polarization is caused to precess at a drive frequency about a magnetic field. A transverse component of the atomic polarization is detected by monitoring the absorption of the edges of a diverging light beam using at least one photodetector. Then the magnitude of the precessing transverse atomic polarization is determined by subtracting signals coming from opposite sides of the light beam.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying figures, in which like reference numerals refer to identical or functionally-similar elements throughout the separate views and which are incorporated in and form part of the specification, further illustrate embodiments of the present invention.

FIG. **1** illustrates a schematic of an apparatus in which one embodiment of the present invention can be implemented.

FIG. **2** illustrates a schematic of the operation of a diverging beam magnetometer in accordance with one embodiment of the present invention.

FIG. **3** illustrates a schematic of the operation of a diverging beam gyroscope in accordance with one embodiment of the present invention.

FIG. **4** illustrates a schematic of an implementation of the diverging beam magnetometer or gyroscope as a micro-electro-mechanical systems ("MEMS") device in accordance with one embodiment of the present invention.

FIG. **5** illustrates a schematic of the basic operation of a co-magnetometer nuclear magnetic resonance ("NMR") gyroscope as a comagnetometer.

FIG. **6** illustrates a schematic of a compact nuclear magnetic gyroscope ("NMRG") in accordance with one embodiment of the present invention.

FIG. **7**(*a*) and FIG. **7**(*b*) illustrate a schematic of the exterior and cross-sectional view of magnetic shields in accordance with one embodiment of the present invention.

FIG. **8**(*a*) and FIG. **8**(*b*) illustrate a schematic of a two-layer flex circuit fabricated on a planar substrate and a flex circuit wrapped around a cylindrical holder to form a set of three-axis coils in accordance with one embodiment of the present invention.

FIG. **9**(*a*), FIG. **9**(*b*), FIG. **9**(*c*), and FIG. **9**(*d*) illustrate a schematic of the main NMRG components, including a NMR cell etched in silicon and bonded between two layers of Pyrex, base plate containing VCSEL and photodiodes with microflex circuit for interconnects, assembled NMRG, and cross-sectional view of assembled NMRG in accordance with one embodiment of the present invention.

FIG. **10**(*a*) and FIG. **10**(*b*) illustrate a schematic of a base plate with flex circuit after the electrical components have been attached and a cross-sectional view of the fabrication process for the base plate with flex circuit in accordance with one embodiment of the present invention.

FIG. **11** illustrates a schematic of a wave plate integration and cell alignment in accordance with one embodiment of the present invention.

FIG. **12** illustrates a system architecture wherein a magnetometer is connected to a computer.

DETAILED DESCRIPTION OF THE INVENTION

The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate embodiments of the present invention and are not intended to limit the scope of the invention.

FIG. **1** illustrates a schematic of an apparatus in which one embodiment of the present invention can be implemented. Shown in the figure is an atomic magnetometer, which could also be operated as a gyroscope under suitable conditions **10**. Light is emitted from a semiconductor laser **20**, such as a vertical-cavity surface emitting laser (VCSEL). It passes through some optics **30** that makes the laser polarization circular, and that may also attenuate the light beam and change its spatial mode. The light then enters an alkali vapor cell **50** with some divergence. The vapor cell contains alkali atoms at their vapor pressure, along with a buffer gas such as N_2 or Ne, which prevents frequent collisions of the alkali atoms with the cell walls. In the gyroscope implementation, there may be an additional noble gas, such as ^{129}Xe, whose nuclei can be polarized via spin-exchange with the alkali atoms. We assume here that the magnetic field, B_0, **70** is oriented along the direction of the average propagation direction of the light field. Alkali atoms in the cell are thereby polarized along this direction by the circularly polarized light field. The transmitted light power is detected by photodetectors **60**.

A set of radio-frequency (RF) coils **40**, positioned about the cell creates an oscillating magnetic field in the cell. When the frequency of this field is tuned to the Larmor frequency, ω_L, of the atoms in the magnetic field, the atomic spins precess coherently about the magnetic field direction. The Larmor frequency of the atoms is related to the magnetic field by $\omega_L=\square B_0$, where □ is the gyromagnetic ratio of the atoms (2□×3.5 Hz/nT in the case of ^{133}Cs and 2□×11.8 mHz/nT in the case of ^{129}Xe). The precessing noble gas spins (if present) create a transverse magnetic field, which affects the alkali spins in a manner that depends on the orientation of the noble gas spin. The precessing alkali spins create a transverse polarization in the atomic vapor, which causes a change in the absorption of the light field that depends on the propagation